Efficacy of EEG-fMRI Neurofeedback in stroke in relation to the DTI structural damage: a pilot study

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Introduction:

If many interventions for motor rehabilitation after stroke are available, recent studies have shown the potential of neurofeedback (NF) (Wang, Mantini and Gillebert, 2017). The majority of these NF approaches have relied solely on one imaging technique: mostly on EEG recordings. If EEG offers the advantages of practicability and high time resolution, it suffers from a limited spatial resolution and access to deeper areas of the brain. This has prompted the effort of exploring the implementation of NF approaches with other sensing techniques such as fMRI (Sitaram et al., 2012), which allows to more precisely identify cortical targets. Recent study have gone further (Zotev et al., 2014; Perronnet et al., 2017), revealing the potential of integrating complementary techniques such as EEG and fMRI to achieve a more specific regulation. In this exploratory work, for the first time multisession bimodal EEG-fMRI NF for upper limb motor recovery was tested in four stroke patients. In particular, the feasibility and functional efficacy of the NF training were investigated with respect to the integrity of the corticospinal tract (CST), a well-established predictor of the potential for clinical improvement.

Methods:

Four chronic stroke patients (54-76 years, 2 females) with left hemiparesis took part to the study. At inclusion, diffusion tensor imaging (30 directions DTI, b0=1000) was performed to assess the asymmetry between ipsilesional and controlesional CST. To this end, the diffusion tensor model was estimated and the fractional anisotropy (FA) calculated. The CST was then reconstructed (Jong et al., 2005) and an index of FA asymmetry between the affected and unaffected CST was calculated. Disruption of the fibers integrity is associated to a FA decrease therefore an index of FA asymmetry gives important indication about the structural deficit. In particular it has been shown that for a FA asymmetry index value greater than 0.25 limited capacity for recovery are expected (Stinear et al., 2007). The experimental protocol for NF training included an alternation of bimodal EEG-fMRI and unimodal EEG NF sessions. We expected that during bimodal NF training the patient, receiving richer and more specific information, could develop a strategy that could then be "transferred" to unimodal EEG sessions. During each NF session, patients alternated 16 20 seconds blocks of rest and motor imagery of the affected upper limb with NF. Information about their brain activity was given to the patients by means of a visual feedback reflecting the EEG and BOLD activity of regions of interest identified in the ipsilesional motor cortex after a preliminary calibration block.

Results:

All the patients were able to self-regulate their brain activity in the motor cortex during the NF training. The analysis of the CST integrity revealed that for 3 patients a high degree of symmetry between ipsilesional and controlesional CST was preserved (FA asymmetry equal to 0.03, 0.06 and 0.05). For one patient however, the ipsilesional CST was more affected, giving an index of FA asymmetry of 0.105, closer to the threshold indicating very poor recovery potential. This patient also failed to up-regulate the brain activity in the ipsilesional motor cortex at the end of the training with respect to the first session (Figure 1). On the other hand, 2 of the 3 patients exhibiting a high degree of integrity of the ipsilesional CST showed significant increased activation of the ipsilesional M1 at the end of the training ($p<<0.001$, Wilcoxon test) and exhibited a larger involvement of the ipsilesional motor and premotor areas. These preliminary findings confirm the critical role of the CST integrity for stroke motor recovery and indicate that this is importantly related also to functional brain regulation of the ipsilesional motor cortex.

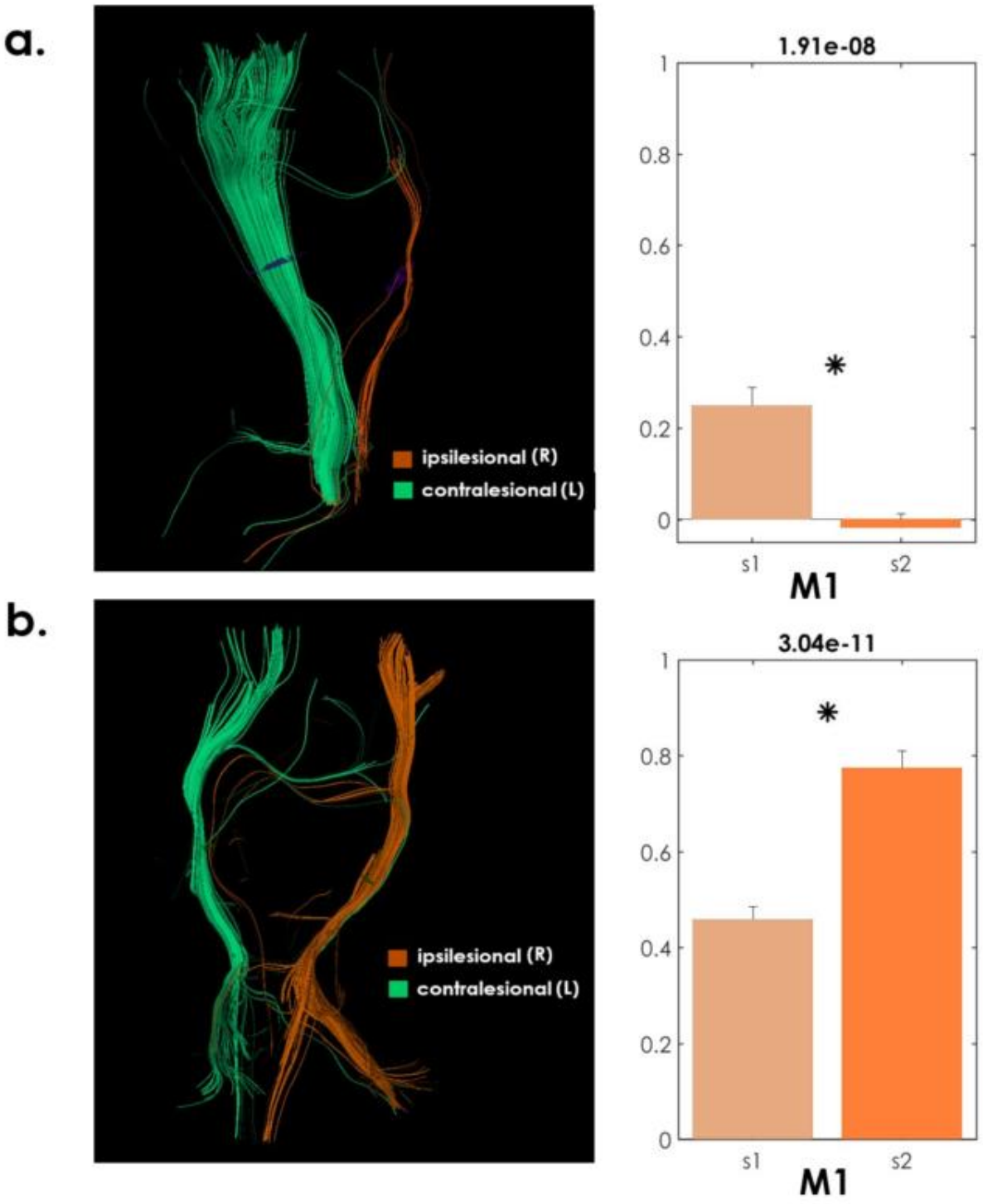

Figure 1. Example of CST reconstruction and primary motor cortex (M1) activation in two patients (a. and b.). Ipsilesional CST is plotted in orange and controlesional CST in green. The bar plot on the right hand side of the figure show the average (and standard error across NF training blocks) of BOLD contrast activation in the primary motor cortex in the first (s1) and second (s2) training session, with relative statistics (Wilcoxon test, p values at the top of the barplots).

Conclusions:

This exploratory study indicates that functional performances are related to CST integrity of and give useful indications for future studies inclusion criteria.

Disorders of the Nervous System:

Stroke

Imaging Methods:

BOLD fMRI [1]
Diffusion MRI
EEG [2]

Learning and Memory:

Neural Plasticity and Recovery of Function

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Electroencephaolography (EEG)
FUNCTIONAL MRI
Motor
STRUCTURAL MRI
Other - Neurofeedback

[1|2]Indicates the priority used for review